OPTIMIZATION OF HYBRID ALUMINIUM METAL MATRIX COMPOSITE THROUGH TAGUCHI METHOD

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Abstract - *Metal matrix composite is one of the reliable sources to meet the demand on engineering materials such as high tensile strength, toughness, hardness, low density and good wear resistance. Aluminium based metal matrix composite used in the areas of aerospace and automotive industries include high performance, economic and environmental benefits. This paper deals with the prediction of machining parameters for aluminium metal matrix reinforced with 5wt% of boron carbide and 6 wt% of flyash in electrical discharge machining through taguchi method. L9 orthogonal array was created to achieve the high metal removal rate and surface roughness with desirable control factors such as current, pulse on time and pulse off time. Predicted result was evaluated by analysis of variance (ANOVA).*

Key words: Metal matrix composite, Aluminium, Boron carbide, Flyash, Electrical Discharge machine, Taguchi method, Analysis of variance.

1. INTRODUCTION

In the past few years, materials development has shifted from monolithic to composite materials for adjusting to the global need for reduced weight, specific strength and high performance in structural materials. Metal matrix composite (MMC) have been attracting in the field of aerospace and automobile industries for their excellent mechanical properties like light weight, high strength, moderate casting temperatures and other properties.

Now a day the need of light weight engineering materials for various engineering applications goes on increasing. To meet such demands aluminium metal matrix composite is one of the optional sources. Aluminium metal matrix composite (AMM) is mostly preferable for their excellent reliable properties such as reduced weight, easy manufacturing methods, wear resistance and corrosion resistance etc.

Manufacturing of aluminium metal matrix composites through two ways, one is solid state manufacturing and another one is liquid state manufacturing. Mostly, the liquid state processing of AMMC's are preferred because of their simplicity and scalability. A metal matrix composite is a combination of two distinct metals to obtain a compounded material known as reinforced material. The reinforcement material is embedded into a matrix and does not serve a purely structural task, but is also used to change the physical properties such as wear resistance, friction coefficient and thermal conductivity.

This work concentrated on machining aluminium based metal matrix composite reinforced with Boron Carbide (B_4C) and Fly Ash by the size of 90 micron.

The advancement in automation and aerospace has made it possible to produce high quality industrial product. Qualities of mechanical products are predicted by poor metal removal rate and surface roughness. Non-Conventional machining process is optional for achieving high quality products. This paper concentrated on machining of aluminium based metal matrix composite by Electrical discharge machining (EDM) through Taguchi Method.

2. LITERATURE REVIEW

Thambu sornakumar and marimuthu kathiresan has been evaluated the surface finish and flank wear in LM24 aluminium alloy and silicon carbide particles by CNC-Milling machine. From the observations, the surface finish is increased with increase in speed and decrease of feed. High speed steel end mill cutters are used for machining process.

M.Kathiresan and T.Sornakumar has been assessed the machining parameters such as metal removal rate (MRR) and Surface finish in Electrical discharge Machine (EDM) for aluminium alloy-silicon carbide composite. Newly vortex techniques and Pressure Die Casting manufacturing methods are founded for metal matrix composite. Among the various control factors, Current was emerged in machining operations and which is clearly shown in table.

Muhammed Hayat Jokhio et al developed the 7xxx series aluminium alloy combined with Cu-Zn-Mg reinforced by Al_2O_3 for achieving the strength. SEM test and Tensile test carried out to find out the porosity and tensile strength. Strength has been increased with increase the aluminium oxide gradually.

K.R.Thangadurai and A Asha resolved the machining characteristics of the Aluminium 6061 reinforced with 5% Boron Carbide. Electrical Discharge Machining control factor such as Current, pulse on time and pulse off time has been accounted to achieve the good surface finish.

Amit Joshi and Pradeep Kothiyal learned the individual response value significance such as metal removal rate through Analysis of variance (ANOVA) in Electrical discharge machining for OHNS EN31 steel.

3. SELECTION OF MATERIALS

3.1 Matrix material

Material selection is one of the important processes for any investigation based on the recent development. Aluminium LM25 is selected as matrix phase, which is used in the automobile industries for their excellent properties like high strength and wear resistance. chemical compounds of light metal aluminium 25 is shown in the table 2.1.

Table -3.1: Chemical compounds of aluminium LM25

Elements	Percentage
Copper (Cu)	0.2
Magnesium (Mg)	0.2-0.6
Silicon (si)	6.5-7.5
Iron (Fe)	0.5
Manganese(Mn)	0.3
Nickel(Ni)	0.1
Zinc(Zn)	0.1
Lead (Pb)	0.1
Tin (Sn)	0.2
Titanium (Ti)	0.2
Aluminium (Al)	Reminder

3.2 Reinforcements

Reinforcements are embedded in the matrix materials to increase the strength and toughness. Most of the researchers are handled the ceramic particles are used as reinforcements. Particle sizes are important factor in the properties of the materials.90micron size particles are selected for metal matrix to decrease the wettability during the solidification process. Boron carbide is most adaptable material for low density material due to their low Specific gravity than aluminium. Boron carbide is good strength and thermal expansion than silicon carbide.

Coal Ash is prepared from thermal power plant for making the construction of home and act as reinforcement for light weight material. It has very low density than boron carbide. Superior properties for materials are maintained by high strength, ductility and wear resistance. Density of the material is important factor for calculating the weight of the composite by selecting the proportion of the metal matrix and reinforcements which is presented in the table 3.2

Table -3.2: various proportions of metal matrix and reinforcements

Materials	Aluminium LM25	Boron Carbide (B_4C)	Fly Ash
Proportions	89 Wt%	5 Wt%	6 Wt%
Density	2680 Kg/m^3	2520 Kg/m^3	721Kg/m^3

4. EXPERIMENTATION PROCESS

4.1 Manufacturing of Metal Matrix Composite

Liquid state manufacturing is reliable and cheaper methods to achieve in the requirement conditions. Among the manufacturing of liquid state manufacturing, Stir casting process is more economic compared with other methods. Aluminium LM25 ingot is cut and poured into ceramic crucible for 850°C, after the stirrer is operated for 200rpm with the stirring duration of 15-20minites.Preheated (200°C) boron carbide and flyash particle with the ratio of 5 and 6 Wt% are mixed gradually with molten metal matrix, which is clearly shown in the figure 4.1.

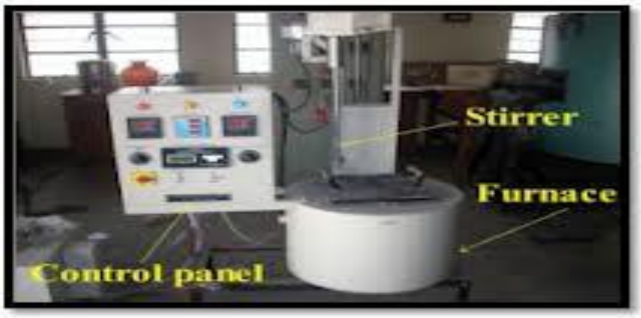

Fig -4.1: Stir Casting Process

Molten aluminium matrix composite are poured into mild steel cast die, which is shown in the figure 4.2

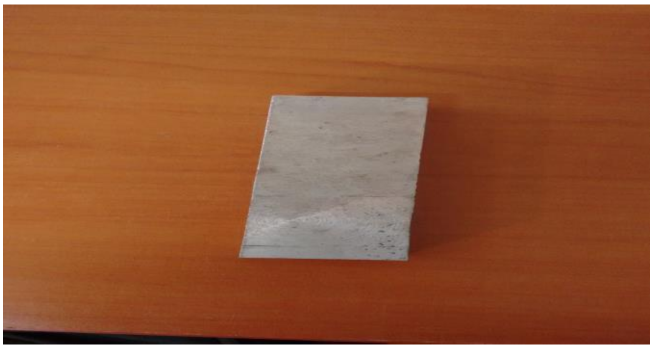

Fig -4.2: aluminium mold piece

4.2 Machining of Metal Matrix composite

The manufacturing process involved in this study is Stir Casting method. The stir casting method is a liquid state method in which the dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir Casting is the simplest and the most cost effective method of liquid state fabrication. A harder and difficult to machine materials such as carbides, stainless steel, nit alloy and many other high strength temperature resistant alloys find wide application in aerospace and nuclear engineering industries. Many of these materials also find applications in other industries, owing to their high strength to weight ratio, hardness and heat resisting qualities. For such materials the conventional edged tool machining is highly uneconomical and the degree of accuracy and surface finish attainable are poor. The unconventional machining processes have been developed to overcome all these difficulties. In unconventional machining process, there is no direct physical contact between tool and work piece. Therefore the tool material need not be harder than the work piece material as in conventional machining. There are various machining process were available. But electrical discharge machining is the most economical one and also it is considered by many researchers. In electrical discharge machining the required metal is removed by producing power full electric spark discharge between the tool (anode) and the work material (anode).

4.3. Experimental Measurements

4.3.1 Metal Removal Rate (MRR)

MRR is a performance measure for the erosion rate of the work piece and is typically used to quantify the speed at which machining is carried out. It is expressed as the volumetric amount of the work piece material removed per unit time. The MRR is calculated by the following expression

$$MRR = \frac{(W_i - W_f) \times 1000}{D_w \times t}$$

4.3.2 Surface Roughness (SR)

Surface quality is the broad performance measure used to describe the condition of the machined surface. It comprises components such as surface roughness (SR), extent of heat zone (HAZ), recast layer thickness and micro crack density.

4.3.3 Design of Experiments (DOE)

Design of experiments using the Taguchi method is employed here in order to find the optimum number of runs required to conduct the experiment with the combinations of parameters. A total of three factors namely current, Pulse on time and pulse off time were considered for the experimental design. Each factor has three levels. A L9 orthogonal array was formed based on the three factors- three level design. The various factors and their levels are listed in the table 4.1

Table 4.1: Factors and Levels

Machining parameter	Symbol	Unit	Levels		
			Level 1	Level 2	Level 3
Current	I_p	A	10	15	20
Pulse on time	T_{ON}	µs	5	6	7
Pulse off time	T_{OFF}	µs	4	5	6

5. RESULT AND DISCUSSION

5.1 Experimental Observations

Based on the selected range of current, pulse on time and pulse off time, the response variable such as metal removal rate and surface roughness are determined which is represented in table 5.1 and table 5.2.

Table -5.1: Experimental observations for MRR

Trial No	MRR (mm^3/min)	SR (µm)
1	3.754	4.329
2	10.451	12.541
3	15.006	6.494
4	21.256	3.932
5	32.412	10.982
6	35.430	8.484
7	25.452	4.588
8	43.517	14.219
9	48.775	10.242

Table -5.2: Experimental Results

Trial No	Current	Pulse on time	Pulse off time	W_t of work piece	
	I_P	μs	μs	W_i	W_f
1	10	5	4	348.856	342.580
2	10	6	5	348.580	347.814
3	10	7	6	347.814	346.715
4	15	5	5	346.715	345.158
5	15	6	6	345.158	342.783
6	15	7	4	342.783	340.187
7	20	5	6	340.187	338.322
8	20	6	4	338.322	335.134
9	20	7	5	335.134	331.560

5.2 Optimization by S/N Ratio

The taguchi method use a statistical measure of performance called signal to noise ratio. The signal to noise ratio can be used to measure the deviation of the performance characteristics from the desire values. Generally there are three categories of performance characteristics in the analysis of the S/N ratio as follows; Calculate S/N Ratio for the corresponding responses using the following formula.

Larger–the–better: This is applied for problem where maximization of the quality characteristic of interest is sought.

$$\text{S/N ratio } (\eta) = -10 \log_{10} \left(\frac{1}{n}\right)\left(\sum_{i=1}^{n} \frac{1}{y_{ij}^2}\right) \text{ ---------- (i)}$$

Where
n = Number of replications
Yij = Observed Response value where i = 1, 2 ....n; j = 1, 2...k

Smaller–the–better: This is termed as the smaller-the-better type problem where minimization of the characteristic is intended.

$$\text{S/N ratio } (\eta) = -10 \log_{10} \left(\sum_{i=1}^{n} \frac{y_{ij}^2}{n}\right) \text{ ------------ (ii)}$$

Based on the observation of results, calculated the larger the better for metal removal rate and smaller the better for surface roughess,which is presented in table 5.3.

Table -5.3: Signal to Noise Ratio for MRR and SR

Trial No	Response Values		S/N Ratio	
	MRR(mm³/min)	SR(μm)	MRR(mm³/min)	SR(μm)
1	0.3754	4.329	11.490	−12.728
2	10.451	12.541	20.383	−21.967
3	15.006	6.494	23.525	−16.250
4	21.256	3.932	26.550	−11.892
5	32.412	10.982	30.214	−20.814
6	35.430	8.484	30.987	−18.572
7	25.452	4.588	28.114	−13.232
8	43.517	14.219	32.773	−23.057
9	48.775	10.242	33.764	−20.208

5.3 Effects of S/N Rato for MRR and SR

Optimal parameter is a main constrain for determining the accurate machining parameters. Signal to noise ratio (S/N) in the taguchi method used to find out such thing with the combination and correlated the experimental results. These parameters are evaluated the most involved control factors from the desirable ranks, which is directly measure the factors for metal removal rate ad surface roughness is illustrated in the table 5.4 & 5.5.

Table -5.4: SN Ratio for MRR

Level	Current	Pulse on Time	Pulse off Time
1	18.17	22.05	25.08
2	29.25	27.79	26.90
3	31.55	29.43	27.28
Delta	13.08	7.37	2.20
Rank	1	2	3

Table -5.5: SN Ratio for SR

Level	Current	Pulse off Time	Pulse off Time
1	-16.37	-14.32	-14.24
2	-11.80	-15.32	-14.94
3	-16.40	-14.94	-15.39
Delta	4.60	1.00	1.14
Rank	1	3	2

From the table 5.4 and 5.5, current is mostly involved for metal removal rate and surface roughness, which is clearly shown from the rank one. Pulse on time and pulse off time are involved in another rank. Internal structure of the metal matrix and reinforcement will be varied due to temperature of micro structure which is control by current, so the current is taken as first rank in the above table.

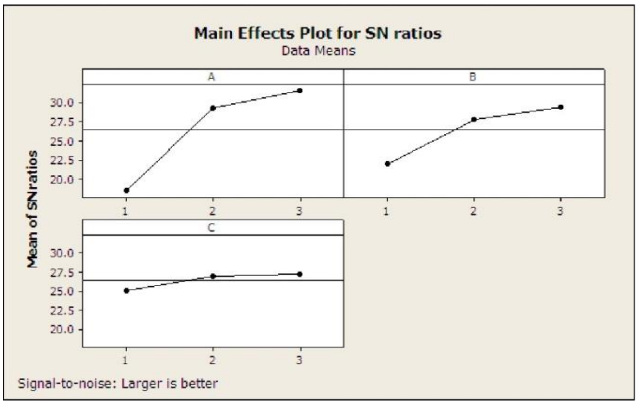

Figure -5.1: SN Ratio for MRR

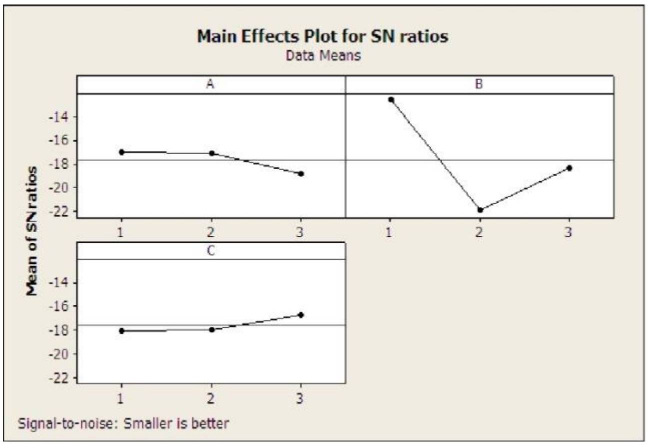

Figure -5.1: SN Ratio for SR

Most of the machining process, current in mainly involved among the various control factors, because current has decided to heat and erode the material by the current density. so the metal removal rate and surface roughness increases with increase the current which is clearly illustrated in the figure 5.1 and 5.2

5.4 Analysis of variance

Analysis of variance is tested at the level of 95%.Most desirable control factors are evaluated by the above confidence level, which is clearly shown in the table 5.6

Table -5.6: ANOVA Table for MRR and SR

Source of Variations	Sum of Squares	Degrees of freedom	Mean Square	F Ratio
Between sample	1426.528	1	1426.528	Fca = 11.60975
Within Sample	1951.2161	16	121.9510	Ftab (1,16) = 4.49

From the observed values, the f ratio is above the f calculated, so there is no null hypothesis. The variance is occurred in the above observed result in the 95% confidence level.

6. CONCLUSION

- This paper offers an experimental perception into the machining properties of aluminium based metal matrix composite reinforcement boron carbide and flyash.
- The experimental result was clearly suggested that the addition of metal removal rate is increased with increases the current.
- Surface roughness was decreased with increase the current.
- From the observed results, among the three control factors such as current, pulse on time and pulse off time, current is mostly involved in the machining responses like metal removal rate and surface roughness.
- Analysis of variance (ANOVA) was helped to find out the variance of the each column and row characteristics at 95% confidence level.

REFERENCES

[1] Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar and Mukhtiaraliunar, 'Manufacturing of aluminium composite material using stir casting Process', Mehran University Research Journal of Engineering & technology,2010,Volume 30,P 53-64.
[2] Thambu sornakumar and Marimuthu Kathiresan, 'Machining Studies of die cast aluminium alloy-silicon carbide composite', International journal of minerals Metallurgy and Materials, 2010, Volume 17, P 648-653.
[3] M.Kathiresan and T.Sornakumar, 'EDM Studies on Aluminium Alloy-Silicon Carbide Composites Developed by Vortex Technique and Pressure Die Casting', Journal of Minerals & Materials Characterization & Engineering, 2010, Volume 9, P 79-88.
[4] Thangadurai, K.R. Asha, A. K , 'Mathematical modeling of surface roughness on machining of AA6061-boron carbide composite in EDM through RSM', International Journal of Mechanical and Materials Engineeirng,2012,Volume 7,P 197-202.
[5] Amit Joshi and Pradeep Kothiyal , 'Investigating effects of process variables on MRR in EDM by using taguchi parameter design approach', International Journal of Theoretical and Applied Research in Mechanical Egineeirng,2012,Volume 1,P 54-59.
[6] Srinivasan.A and Arunachalam et al, 'Machining Performance study on Metal Matrix Composites-A Response Surface Methodology Approach, American Journal of Applied sciences,2012,Volume 9, P 478-483.
[7] Raghuraman.S and Thiruppathi.T et al, 'Optimization of EDM parameters using taguchi method and grey relational analysis for mild steel IS 2026',International Journal of Innovative Research in science, Engineering and Technology,2013,Volume 2,P 3095-3104.
[8] Lakhvir Singh, and Baljinder Ram et al , 'Optimization of Process Parameters for Stir casted aluminium Metal Matrix Composite using taguchi method', International Journal of Research in Engineering and Technology,2013,Volume 2,P 375-383.
[9] Ashvarya Agarwal and Avanish Kumar et al, 'Modeling and optimization of tool Wear rate in Powder Mixed EDM of MMC',2nd International conference on Mechanical and Robotics Egineering,2013,P1-6.
[10] Rajesha.S, and Jawalkar C.S et al ,'Study of Recast Layers and Surface Roughness on Al-7075 Metal Matrix Composite during EDM Machining during EDM machining', International journal of Recent advances in Mechanical Egineering,2014,Volume 3,P 53-62.
[11] Kannan.S and Ramanathan.K, 'Optimization of EDM parameter of Al-Tic composite using taguchi methodology', Middle-East Journal of Scientific Research, 2014, volume 22, P 121-127.

[12] Rajesh Kumar Bhuyan, Routara, B.C, et al, 'Parametric optimization of Al-Sic12% Metal Matrix Composite Machining by Electrical Discharge Machining',5th International & 26th All India manufacturing technology, Design and Research Conference,2014,P 345-1 to 345-6.